

## PROJECT SUMMARIES

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### FREE ELECTRON LASER DAMAGE FOR SHIP DEFENSE

W. B. Colson, Distinguished Professor

Department of Physics

Sponsor: Thomas Jefferson National Accelerator Facility and Naval Postgraduate School

**OBJECTIVE:** Research the laser damage from a free electron laser with short picosecond pulses.

**SUMMARY:** The power density required for defense against sea-skimming missiles is 10 kW per square centimeter. The free electron laser at Thomas Jefferson National Accelerator Facility was used at the required power density to observe and measure the damage to several types of materials. The damage rates were analyzed with the goal of determining whether the unique short pulse format of the free electron lasers would damage materials more efficiently than the more typical cw laser.

#### PUBLICATIONS:

Colson, W.B., "Short-Wavelength Free Electron Lasers in 2000," *Nuclear Instruments and Methods in Physics Research*, (to be published in 2001.)

Thomson, R.W., Jr., Short, L.R., McGinnis, R.D., Colson, W.B., Shinn, M.D., Gubeli, J.F., Jordan, K.C., Hill, R.A., Biallas, G.H., Walker, R.L., Neil, G.R., Benson, S.V., and Yunn, B.C., "TJNAF Free Electron Laser Damage Studies," *Nuclear Instruments and Methods in Physics Research*, (to be published in 2001.)

McGinnis, R.D., Thomson, R.W., Jr., Short, L.R., Herbert, P.A., Lampiris, D., Christodoulou, A., Colson, W.B., Shinn, M.D., Neil, G.R., Benson, S.V., Gubeli, J. F., Evans, R., and Jordan, K.C., "Free Electron Laser Material Damage Studies," Naval Postgraduate School Technical Report, NPS-PH-01-001, 2000.

#### PRESENTATION:

Colson, W.B., "Short-Wavelength Free Electron Lasers in 2000," poster paper at the Twenty Second International Free Electron Laser Conference, Duke University, Durham, NC, August 2000.

#### THESIS DIRECTED:

McGinnis, R.D., "Free Electron Laser Development for Directed Energy," Ph.D. Dissertation, Naval Postgraduate School, September 2000.

**DoD KEY TECHNOLOGY AREAS:** Modeling and Simulation, Directed Energy Weapons

**KEYWORDS:** Free Electron Laser, Industrial Laser Processing

### HIGH POWER FREE ELECTRON LASER FOR SHIP DEFENSE

W. B. Colson, Professor

Department of Physics

Sponsor: Naval Sea Systems Command

**OBJECTIVE:** In order to develop the technology for using free electron lasers to defend ships against sea-skimming missiles, the high average power infrared wavelength free electron laser at the Thomas Jefferson National Accelerator Facility, Newport News, VA is studied.

**SUMMARY:** The Jefferson National Accelerator Facility has developed superconducting accelerator to power a free electron laser with infrared wavelengths. We studied design modifications that would increase the laser power from 1,700 Watts to 10,000 Watts. NPS research studied the inverse tapered undulator with the goal of taking the free electron laser to higher average power.

## PROJECT SUMMARIES

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### PUBLICATIONS:

Colson, W.B. and McGinnis, R.D., "The Free Electron Laser With Inverse Taper," *Nuclear Instruments and Methods in Physics Research*, 49-52, 2000.

McGinnis, R.D., Blau, J., Colson, W.B., Massey, D., Crooker, P.P., Christodoulou, A., and Lampiris, D., "Simulations of the TJNAF 10kW Free Electron Laser," *Nuclear Instruments and Methods in Physics Research*, (to be published in 2001).

Christodoulou, A., Lampiris, D., Colson, W.B., Crooker, P.P., Blau, J., McGinnis, R.D., Benson, S.V., Gubeli, J.F., Neil, G.R., "Simulations of the TJNAF FEL With Tapered and Inversely Tapered Undulators," *Nuclear Instruments and Methods in Physics Research*, (to be published in 2001).

### PRESENTATIONS:

Colson, W.B. and McGinnis, R.D., "The Free Electron Laser With Inverse Taper," poster paper at the Twenty Second International Free Electron Laser Conference, Duke University, Durham, NC, August 2000.

McGinnis, R.D., Blau, J., Colson, W.B., Massey, D., Crooker, P.P., Christodoulou, A., and Lampiris, D., "Simulations of the TJNAF 10kW Free Electron Laser," poster paper at the Twenty-Second International Free Electron Laser Conference, Duke University, Durham, NC, August 2000.

Christodoulou, A., Lampiris, D., Colson, W. B., Crooker, P.P., Blau, J., McGinnis, R.D., Benson, S.V., Gubeli, J.F., and Neil, G.R., "Simulations of the TJNAF FEL With Tapered and Inversely Tapered Undulators," poster paper at the Twenty Second International Free Electron Laser Conference, Duke University, Durham, NC, August 2000.

### THESES DIRECTED:

Massey, D.S., "Simulations of Darmstadt Free Electron Laser and a Comparison of High Gain Free Electron Lasers," Masters Thesis, Naval Postgraduate School, September 2000.

Christodoulou, A., "Simulations of the TJNAF Free Electron Laser With Negative Taper and Laser Damage Studies," Masters Thesis, Naval Postgraduate School, September 2000.

Lampiris, D., "Simulations of the TJNAF Free Electron Laser With a Tapered Undulator and Experimental Results of Laser Damage," Masters Thesis, Naval Postgraduate School, September 2000.

**DoD KEY TECHNOLOGY AREAS:** Modeling and Simulation, Directed Energy Weapons

**KEYWORDS:** Free Electron Laser, Industrial Laser Processing

### INFRA-RED RESEARCH: THERMAL IMAGING MODELS

**A.W. Cooper, Professor**

**Department of Physics**

**Sponsor: Naval Sea Systems Command**

**OBJECTIVE:** To evaluate the potential of polarization filtering in target discrimination range improvement in FLIR imagery, and to compare available TDA FLIR range prediction models for potential joint service use. This project is continuing.

**SUMMARY:** NPS polarized measurements showed improved IR target/background contrast for ship targets. Previous TDA models to demonstrate improvement in target detection or identification ranges have been inconsistent in the treatment of target and sea radiances, and results have been inconclusive.

## PROJECT SUMMARIES

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During this year modeling was improved with the addition of the MUSES (MultiService Electro-optic Signature) ship signature model and an operational polarized MRTD function for the sensor. The polarized version of the SEARAD code was used for sea and atmospheric extinction and path radiance. A Mid Latitude Summer at sea weather file predicted 33.5% increase in detection range. +2% and +8% degree of polarization (i.e. plane of polarization vertical) on the target increased this to 35.6% and 39.8% respectively. This model should now be applied for other targets and climatic conditions. The U.S. Army ACQUIRE Tactical Decision Aid FLIR field performance code was compared to the Navy/Air Force WinEOTDA code for Joint Service operations in littoral waters, using a naval target and a weather data set from the Gulf of Oman. Differences in the inputs, algorithms, and predictions of the codes were analyzed, using a FLIR92 model output for a generic second-generation sensor in both models. WinEOTDA showed consistently longer detection ranges than ACQUIRE, and were significantly more sensitive to sensor altitude, but less sensitive to target aspect angle.

### **THESES DIRECTED:**

Celalettin, G., "Evaluation of Tactical Decision Aid Programs for Prediction of Field Performance of IR Sensors," Masters Thesis, Naval Postgraduate School, September 2000.

Yildirim, M.Y., "Modeling Second Generation FLIR Sensor Detection, Recognition and Identification Range with Polarization Filtering," Masters Thesis, Naval Postgraduate School, September 2000.

**DoD KEY TECHNOLOGY AREAS:** Sensors, Battlespace Environments, Modeling and Simulation

**KEYWORDS:** Atmospheric Optics, Infrared Sensors, FLIR, TDA

### **SPECTRAL IMAGERY IN THE NEAR-ULTRAVIOLET**

**D.S. Davis, Associate Professor**

**Department of Physics**

**Sponsor: Defense Intelligence Agency**

**OBJECTIVE:** The objectives of this project were to continue calibrations of the Naval Postgraduate School Ultraviolet Imaging Spectrometer (NUVIS) and to undertake the development of an improved next generation UV imaging spectrometer.

**SUMMARY:** Most of the project's objectives were met. When we completed the analysis of the sulfur dioxide calibration data recorded by NUVIS, it was realized that substantial gaps remain in the available spectral abundance data set, both in the published literature and our in-house data. Those gaps are in both the extremely low-abundance and middle-high abundance regimes. Therefore, during the spring and summer of CY01 we are going to attempt to fill in those gaps. Development of a next-generation successor instrument, now designated as LINUS (Lineate Imaging Near-ultraviolet Spectrometer) are proceeding well. The optical subsystems of the instrument have been completely designed, and we are awaiting the delivery of some custom-fabricated components from an external supplier. The mechanical and opto-mechanical designs of LINUS are now complete, and about 75% of the hardware has been procured or fabricated in-house. We currently plan "first light" tests in late spring of 2001, with field test to follow by late summer.

### **THESIS DIRECTED:**

Kompatzki, R.C., "Design and Development of the Image Scanner for the Lineate Imaging Near-ultraviolet Spectrometer (LINUS)," Masters Thesis, Naval Postgraduate School, December 2000.

### **OTHER:**

The following project deliverables have been produced, but are considered proprietary to the project: 1) High resolution platinum hollow cathode emission line spectra for UV wavelength calibrations, covering

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## PROJECT SUMMARIES

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the entire near-ultraviolet spectral region. The voluminous plots and tabulated data have been generated from the NIST Atomic Data online database. 2) *Mathematica* computer software to generate and to display the platinum data. 3) Extensive optical design studies for LINUS, using *Optica* and *ZEMAX*. A set of opto-mechanical and mechanical design drawings, in *AutoCAD* form, for LINUS

**DoD KEY TECHNOLOGY AREAS:** Sensors

**KEYWORDS:** Sensors, Optics, Ultraviolet, Environmental Monitoring, Remote Sensing

### SINKING OF A BODY DUE TO BUBBLES

Bruce Denardo, Associate Professor

Department of Physics

Sponsor: Naval Postgraduate School Research Initiation Program

**OBJECTIVE:** A closed body floats in a fluid when its average density is less than the density of the fluid. If gas bubbles are introduced into a liquid, the average density of the resultant fluid is reduced. If this new density is less than that of the body, then one might think that the body would sink. However, the bubbles also produce upward forces on the body, due to drag produced by the entrained flows in the fluid, and bubbles sticking to the body. It is thus not obvious whether the introduction of the bubbles can cause a floating body to sink, or, if sinking does occur, what the value of the average fluid density is required relative to the density of the body. Further uncertainty exists due to the substantial amount of turbulence that would occur. This possible sinking effect has been suggested as the cause of the demise of some ships: Large deposits of methane gas under the ocean floor could erupt and the resultant bubbles might sink a ship on the surface. Our objective was to measure the average fluid density required to sink a body, and to compare this to the average density of the body for different values of this density. This is necessary if a reliable prediction is to be made regarding the amount of bubbles that a ship can tolerate before sinking. Of future interest is the effect of bubbles on reducing the buoyant force on submerged bodies such as submarines and divers.

**SUMMARY:** We performed experiments to accurately measure the critical average fluid density of bubbly water required to barely sink a spherical body. The average density of the body was varied from 0.99 to 0.75 the density of water. Bubbles were generated over the entire cross section of the water column, which we refer to as a *closed* environment. A theory was developed to predict the critical average fluid density. The theory assumed a "shadow" region directly above the body where there are no bubbles, and neglected any drag or other possible forces other than static buoyancy. The experimental data are in reasonable agreement with the theory for low airflow rates. At greater airflow rates, the experimental average fluid density is less than the predicted value, which may be due to bubbles entering the shadow region as a result of turbulence. We also investigated bubbles in an *open* environment, which more accurately models the situation in an ocean. In this case, there was expected to be a much greater upward drag force on the body due to circulatory flow. However, our preliminary experiments indicated that this is not true. Further investigations are needed to resolve this.

#### PUBLICATION:

Denardo, B., Pringle, L., DeGrace, C., and McGuire, M., "When Do Bubbles Cause a Floating Body to Sink?" to be submitted to *American Journal of Physics*, 2001.

#### THESES DIRECTED:

DeGrace, C., "Sinking a Body With Bubbles in Closed and Open Environments," Masters Thesis, Naval Postgraduate School, December 2000.

Pringle, L., "Experimental Investigation of Sinking a Buoyant Body in Water with Bubbles," Masters Thesis, Naval Postgraduate School, June 2000.

## PROJECT SUMMARIES

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**DoD KEY TECHNOLOGY AREAS:** Other (Bubbly Liquids)

**KEYWORDS:** Bubbly Liquids, Buoyancy

### PARAMETRIC EXCITATION

**Bruce Denardo, Associate Professor**

**Department of Physics**

**Sponsor: Naval Postgraduate School Research Initiation Program**

**OBJECTIVES:** To investigate the feasibility of exciting a sound mode in a gas-filled resonator by parametric excitation (modulating a parameter upon which the resonance frequency depends). For this to occur, the drive amplitude must be greater than a threshold value that is inversely proportional to the quality factor of the mode. When this condition is met in any oscillator, the response amplitude grows exponentially until it is saturated by a nonlinearity of the system. Hence, large response amplitudes may be possible. This research may thus lead to the use of parametric drives in various practical devices such as thermoacoustic refrigerators, acoustic compressors, acoustic pumps, and intense underwater sound sources.

**SUMMARY:** Parametric excitation was previously attempted for a double Helmholtz resonator (two cavities connected by a neck). The threshold for excitation was not obtained due to the interesting fact that the quality factor of the mode decreased as a result of turbulence generated by the drive. This was the dissertation research of University of Mississippi Ph.D. candidate Wayne Prather (1999), whose work I supervised. An NPS student and I are currently conducting feasibility analyses of parametric excitation in longitudinal and cylindrical resonators that are geometrically modulated. We will also investigate the possibility of pulsing the medium of a resonator with microwaves or a laser.

**DoD KEY TECHNOLOGY AREAS:** Other (Acoustical Resonators, Nonlinear Oscillations)

**KEYWORDS:** Parametric Excitation, Parametric Instability, Nonlinear Oscillations

### NON-RADIATING WAVE SOURCES

**Bruce Denardo, Associate Professor**

**Department of Physics**

**Sponsor: Naval Postgraduate School Research Initiation Program**

**OBJECTIVES:** A nonradiating wave source is one that generates waves over some region, but where no waves propagate outside the region. The nonradiation is not due to nonuniformity of the medium, but to destructive interference of the waves in the region of the source. Surprisingly, nonradiating sources have been predicted to exist, although none have been observed. Our goal was to construct several types of vibrating wire apparatus and observe nonradiating sources in one dimension. The work is important because it will indicate the extent to which nonradiating sources can occur in actual systems. Another objective was to perform numerical simulations in which the realistic effects of dissipation, nonuniformity, and nonlinearity are included. A possible future objective is to theoretically investigate nonradiating sources in two and three dimensions, and to explore the possibility applying the results to reduce the acoustical and electromagnetic emissions of vehicles such as submarines.

**SUMMARY:** We constructed an apparatus in which nichrome (resistive) wire is held under tension by a hanging weight, and an oscillatory current is fed through the wire. Part of the wire lies between the pole faces of a magnet, which exerts an oscillating force on the current in the wire. When the frequency of the current corresponds to an integral number of wavelengths over the length of the forcing region, nonradiation is predicted to occur: the wire should oscillate in the driven region, but be motionless outside this region. If the amplitude of the current is sufficiently large, the wire glows uniformly in the motionless region. The wire is cooled in regions where it is in motion, which reduces the glow. We observed the lowest two nonradiating excitation in this way. We also conducted extensive numerical simulations of nonradiating sources on a mass-and-spring lattice. In the ideal case in which dissipation, nonuniformity,

## PROJECT SUMMARIES

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and nonlinearity are not present, our simulations are in essentially exact agreement with the theory. The presence of any of these effects causes radiation to “leak” from the driven region. Adjustments of the drive frequency and amplitude were shown to minimize this radiation.

### **PRESENTATION:**

Denardo, B., “Nonradiating Wave Sources,” contributed talk at Joint Meeting of Northern California/Nevada Sections of the American Association of Physics Teachers, Stanford University, Palo Alto, CA, 7-8 April 2000.

### **THESIS DIRECTED:**

Miller, G., “Observations of Quasi-Nonradiating Wave Sources in One Dimension,” Masters Thesis, Naval Postgraduate School, June 2000.

**DoD KEY TECHNOLOGY AREAS:** Other (Nonradiating Waves)

**KEYWORDS:** Nonradiating Waves, Noise Cancellation, Inverse Problem

### **EXECUTION OF TOTAL SHIP SYSTEMS ENGINEERING**

#### **MEMORANDUM OF AGREEMENT**

**Robert C. Harney, Senior Lecturer**

**Department of Physics**

**Charles N. Calvano, Professor**

**David W. Byers, Visiting Professor**

**Department of Mechanical Engineering**

**Sponsor: Naval Sea Systems Command**

**OBJECTIVE:** Continue the development of the interdisciplinary Total Ship Systems Engineering (TSSE) Program, exploring added opportunities for state-of-the-art education of officer students, increasing connectivity with operational analysis efforts in the Navy, fostering research into total ship systems engineering problems and processes, maintaining continuity and in-depth experience in the faculty, supporting NAVSEA in its efforts to conceive and explore future ship innovations, and working with NAVSEA to make the annual TSSE student capstone design project relevant to Navy needs.

**SUMMARY:** This is a multi-year activity. In CY2000, the TSSE faculty participated in numerous visits and discussions with NAVSEA and other key individuals involved in the “future Navy” to obtain programmatic guidance and foster relevance. These discussions included individuals at Headquarters NAVSEA, NSWC Carderock and Port Hueneme Divisions, the Naval Warfare Development Command, the Naval Undersea Warfare Center, the CNO Strategic Studies Group, the CNO Executive Panel, Marine Corps Concepts Development Center, and several departments of N8. The final report for the CY99 TSSE capstone design project (a surface warfare test ship) was completed and delivered to its NSWC Port Hueneme customer in January 2000. At the customer invitation, the TSSE faculty participated in a panel discussion on battlefield interoperability at an American Society of Naval Engineers meeting in June 2000. In light of the major efforts to define a Navy after Next, the FY2000 TSSE capstone design project was aligned with the Capabilities of the Navy After Next (CNAN) Study being promoted by the Naval Warfare Development Command. The students designed a combatant (called SEA LANCE) who was capable of laying the Expeditionary Grid (of remote sensors and remote-controlled weapons, which was briefed to a number of groups in December 2000. The final report will be delivered in March 2001. During the conduct of the TSSE project, the students involved other faculty at NPS to a greater degree than previously attempted. NPS’ naval architects, electric power, radar cross-section, and naval campaign analysts all contributed substantially to the success of the project. To facilitate faculty development, a round-robin faculty exchange was arranged for September 2000 to August 2001. Professor Calvano went to the Royal College of Military Science at Shrivenham UK to teach systems engineering and understand the UK approach to systems engineering. David Byers was in turn assigned from Carderock to NPS to take over

## PROJECT SUMMARIES

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Calvano's ship design courses. This is the first step in a more formal and lasting relationship between TSSE and NSWC Carderock. The first volume of a four-volume sequence on the science of combat systems was completed in time to be used in the first course of the CY2001 TSSE program sequence. Further improvements to the TSSE laboratory in the way of computing equipment and presentations equipment were also made.

### **PUBLICATIONS:**

Calvano, C., Harney, R., Wickersham, D., Farsaris, I., Malone, P., Ruley, D., York, N., "The Surface Warfare Test Ship," Naval Postgraduate School Technical Report, NPS-ME-00-001, January 2000.

Harney, R., *Combat Systems Vol. 1: Sensor Functional Characteristics*, Naval Postgraduate School, 545 pp., October 2000. Internally published book used in TSSE and SEI courses.

**DoD KEY TECHNOLOGY AREAS:** Surface/Under Surface Vehicles–Ships and Watercraft

**KEYWORDS:** Sea Lance, Survivability, Total Ship Systems Engineering, Navy After Next

### **NAVY AFTER NEXT PLATFORM INVESTIGATION**

**Robert C. Harney, Senior Lecturer**

**Department of Physics**

**Charles N. Calvano, Professor**

**David W. Byers, Visiting Professor**

**Department of Mechanical Engineering**

**Sponsor: Naval Undersea Warfare Center-Newport Division**

**OBJECTIVE:** Assist the Naval Warfare Development Command in its studies of Capabilities for the Navy After Next (CNAN) through direct participation by Total Ship Systems Engineering (TSSE) students and faculty in program activities.

**SUMMARY:** This is a continuing project. In CY2000, the TSSE program (faculty and students) functioned as a full member of the CNAN program team. The TSSE faculty (and some students) attended meetings and contributed to the platform design and expeditionary grid subteams. The entire TSSE output in the second half of CY2000 was directed at developing a design of a combatant (called SEA LANCE) which is capable of laying the Expeditionary Grid (of remote sensors and remote-controlled weapons. This design consists of a novel combatant-plus-tow architecture. Both combatant and tow employ a novel wave-piercing catamaran design. The tow carries all of the grid elements as defined in the Toolbox developed by the Expeditionary Grid team. Grid elements are deployed by gravity feed out the bottom between the twin hulls. Once grid deployment is complete, the combatant can abandon the empty tow and become a 450-ton, 38-knot missile patrol boat carrying a variety of sensors, four large antiship missiles, and over 50 dual-purpose short-range anti-surface and anti-aircraft missiles. A 10-boat squadron of Sea Lance ships carries more air defense and antiship weaponry than the combined surface combatant ships of a carrier battle group, providing considerable additional capability and flexibility to the battle group commander. The Sea Lance concept has met an extraordinarily favorable reception. The concept has been briefed through the CNAN team, the Naval Warfare Development Command, and all the way to the CNO. Further action is awaiting the delivery of the final report (in March 2001). A *USNI Proceedings* article describing the concept should also be ready for submission in the same time frame.

### **PUBLICATION:**

Calvano, C., Byers, D., Harney, R., Papoulias, F., Ciezki, J., Markle, H., Trevisan, R., Barney, T., Eimers, K., Farman, G., Altekin, A., Kompatzki, R., and Nash, C., "Sea Lance Littoral Warfare Small Combatant System," Naval Postgraduate School Technical Report, NPS-ME-01-001, January 2001.

## PROJECT SUMMARIES

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Harney, R., "The Enemy's Access Denial System: Potential Competitor Exploitation of U. S. Military Vulnerabilities," Naval Postgraduate School Technical Report, NPS-JW-01-014, 413 pp., December 2000.

**DoD KEY TECHNOLOGY AREAS:** Surface/Under Surface Vehicles–Ships and Watercraft

**KEYWORDS:** Sea Lance, Expeditionary Grid, Total Ship Systems Engineering, Navy After Next, Combatant

### **DEVELOPMENT OF HIGH-PRESSURE MINIATURIZED THERMOACOUSTIC REFRIGERATION PROTOTYPE**

**Thomas Hofler, Associate Professor**

**Department of Physics**

**Sponsor: Rockwell Science Center**

**OBJECTIVE:** The technical objective of this CRADA is the fabrication of a miniaturized TAR device compatible with operation at elevated pressures. To enable this evaluation, NPS will build in accordance with Rockwell Science Center specifications and deliver to RSC a functional miniature TAR prototype capable of operating at elevated pressures. RSC is pursuing separate R&D activities complementary to the proposed work, and the elevated-pressure prototype will be used by RSC for comparison with the results of alternative research and development efforts being pursued by RSC, to provide quantitative technical information on potential future paths for performance enhancement.

**SUMMARY:** Thermoacoustic Refrigeration represents an attractive phenomenon for thermal management purposes. Due to the absence of purely mechanical components, it has the potential for miniaturization to support chip-level cooling of electronic components. The performance and efficiency of these miniaturized Thermoacoustic Refrigerators (TAR) will depend strongly on a number of different parameters with one important factor being the operating pressure of the working fluid. To permit characterization of the effects of pressure on the performance of miniaturized TAR devices, NPS shall build according to RSC specifications and deliver to RSC a functional miniature TAR prototype capable of operating at elevated pressures. The elevated-pressure prototype will be used by RSC for comparison with the results of alternative research and development efforts being pursued by RSC, to provide quantitative technical information on potential future paths for performance enhancement. The proposed collaboration offers a mechanism for NPS personnel to apply their established expertise in thermoacoustics to this miniaturized applications area.

**DoD KEY TECHNOLOGY AREAS:** Other (Thermoacoustics)

**KEYWORDS:** Thermoacoustic Refrigerators (TAR), Miniaturized, High-Pressure

### **MATCHED FILTER NON-COHERENT COMMUNICATIONS FOR MODEMEX**

**Thomas Hofler, Associate Professor**

**Kevin Smith, Associate Professor**

**Andres Larraza, Associate Professor**

**Department of Physics**

**Sponsor: Space and Naval Warfare Systems Center-San Diego**

**OBJECTIVE:** To test matched filter detection methods for underwater acoustic modem applications, in the laboratory, and provide signal information for at-sea testing. Results will be compared to time reversed acoustic methods currently being researched in our laboratory.

**DoD KEY TECHNOLOGY AREAS:** Other (Underwater Acoustics)

**KEYWORDS:** Telesonar, Underwater Modem, Digital Communication

## PROJECT SUMMARIES

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### ENVIRONMENTALLY ADAPTIVE SONAR TECHNOLOGIES

Andrés Larraza, Associate Professor

Kevin B. Smith, Associate Professor

Department of Physics

Sponsor: Office of Naval Research

**OBJECTIVE:** To examine Navy relevant applications of the phenomenon of time-reversal acoustics. This phenomenon takes advantage of the incorporation of waveguide effects into the acoustic field to adaptively remove the influence of the environment through re-transmission of a time-reversed transmission. Considered as part of this project were enhancements to active sonar detection algorithms and underwater acoustic communication systems.

**SUMMARY:** In FY00, several activities took place under this project. Numerical algorithms were employed to study and compare the fundamental aspects a two-way communication scheme using time-reversal acoustics (TRA) and a one-way communication scheme using match-filtering techniques. Numerical work also was done on modeling the effectiveness of TRA applied to active sonar systems to enhance detection of submerged targets. Both, the sonar technology and the communications algorithms were implemented in the long tank in SP 017, providing real data to assess the effectiveness of the TRA and match-filtering approaches to underwater acoustic communication systems, and to environmentally adaptive sonar technologies.

#### PUBLICATIONS:

Larraza, A. and Smith, K.B., "Underwater Acoustic Communications Using Time-Reversal Acoustics and Match-filtering Techniques," *Proceedings of the 1<sup>st</sup> Workshop em Acústica Submarina*, Instituto de Pesquisas de Marina, Rio de Janeiro, Brazil, 8-10 November 2000.

Heinemann, M., Larraza, A., and Smith, K.B., "Experimental Studies of Applications of Time-Reversal Acoustics to Non-coherent underwater communications," *Journal of the Acoustical Society of America*.

Smith, K.B., Abrantes, A.A.M., and Larraza, A., "Examination of Time-Reversal Acoustics in Shallow Water and Applications to Non-coherent Underwater Acoustics Communications," *Journal of the Acoustical Society of America*.

#### PRESENTATIONS:

Larraza, A. and Smith, K.B., "Experimental and Numerical Studies of Underwater Acoustic Communication Using Time Reversal Acoustics," ONR Environmentally Adaptive Sonar Technologies (EAST) Peer Review, Applied Research Laboratories, University of Texas, Austin, TX, 8-11 February 2000.

Larraza, A., Smith, K.B., and Shipley, M., "Time Reversal Acoustic Methods Applied to Active Sonar and Underwater Communications," ONR Active Sonar Signal Processing Peer Review, University of Washington, 22-24 August 2000.

#### THESES DIRECTED:

Winter, T., "Numerical Evaluation of Active Sonar System Processing Using Time-Reversal Acoustics Methods," Masters Thesis, Naval Postgraduate School, March 2000.

Heinemann, M., "Experimental Studies of Applications of Time-Reversal Acoustics to Non-coherent Underwater Communications," Masters Thesis, Naval Postgraduate School, March 2000.

**DoD KEY TECHNOLOGY AREAS:** Command, Control and Communications, Computing and Software, Modeling and Simulation

## PROJECT SUMMARIES

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**KEYWORDS:** Underwater Acoustic Communication, Littoral Environments, Time-Reversal Acoustics

### **DEVELOPMENT OF A SEISMO-ACOUSTIC SONAR FOR THE DETECTION OF BURIED MINES IN THE SURF AND NEAR-SURF ZONES**

**Thomas G. Muir, Research Professor**

**Steven R. Baker, Associate Professor**

**Department of Physics**

**Clyde L. Scandrett, Associate Professor**

**Department of Mathematics**

**Sponsor: Office of Naval Research**

**OBJECTIVE:** To develop and investigate the feasibility of the use of a sonar system using guided seismo-acoustic interface waves to detect buried mines in the surf and near-surf zones. This project is supported by ONR Code 322W. NIFR funds were used to partially support Professors Baker and Scandrett. Objectives for their work were to: 1) develop a low-cost, multiple input and output channel data acquisition and analysis system; 2) build up source and receiving arrays of seismic transducers; and 3) theoretically model the seismic array by means of a time domain finite difference model which could be used for a variety of physical settings and input responses.

**SUMMARY:** The hardware portion of a 32-input-channel, 32-output-channel data acquisition and analysis system was built using 16 ganged, professional audio PC sound cards, to be controlled under MATLAB. For the first time, 16 PC sound cards have been integrated into a single system. Some integration problems were encountered, but these were either solved by replacing hardware or were worked around. A problem with card-to-card synchronization, when running under MATLAB, remains to be solved.

We have made arrangements to borrow at least 5 waterproof shakers from the Navy, for use in a source array. We have designed and begun to build a set of 16 3-axis seismometers, to be deployed as a receiving array. Both these arrays will be integrated with the data acquisition/analysis system.

A 3D second order in time and space finite difference code has been developed and written for determining the time dependent displacements of an elastic half space in the vicinity of a source (or sources) and buried inhomogeneities. A new dipolar radiation condition, which handles body and Rayleigh waves, has been designed for use in truncating the numerical domain but is yet to be made fully stable.

### **PUBLICATIONS:**

Sheetz, K., Guy, J., Baker, S., and Muir, T., "Seismic Sonar: The Spatial Coherence of Interface Waves in Surf Zone Sediments," *Proceedings of the 4<sup>th</sup> International Symposium on Technology and the Mine Problem*, Naval Postgraduate School, Monterey, CA, 13-16 March 2000.

Sheetz, K., Guy, J., Baker, S., and Muir, T., "Seismic Sonar: Beamforming in the Sand," *Proceedings of the 4<sup>th</sup> International Symposium on Technology and the Mine Problem*, Naval Postgraduate School, Monterey, CA, 13-16 March 2000.

### **THESES DIRECTED:**

Sheetz, K., "Advancements in Buried Mine Detection Using Seismic Sonar," Masters Thesis, Naval Postgraduate School, December 2000.

Plager, W.L., "Mine Burial in the Surf Zone," Masters Thesis, Naval Postgraduate School, September 2000.

**DoD KEY TECHNOLOGY AREAS:** Battlespace Environments

**KEYWORDS:** Seismic Sonar, Rayleigh Waves, Mine Detection, Surf Zone, Mine Countermeasures

## PROJECT SUMMARIES

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### SENSOR FUSION FOR TERRAIN CATEGORIZATION AND TARGET CLASSIFICATION

**Richard C. Olsen, Associate Professor**

**Department of Physics**

**Sponsor: Center for Reconnaissance Research**

**OBJECTIVE:** The proposed research is to study the utility of data from National Technical Means (NTM) for Terrain Categorization (TERCAT). Data from visible, IR, and radar systems will be acquired in modes available to operational users, and analyzed according to the techniques currently in use for the interpretation of spectral imagery. Techniques in multi-temporal analysis will be added to current work.

**SUMMARY:** Analysis was completed on multi-system fusion, and high accuracy rates were obtained in scene classification.

**THESIS DIRECTED:**

Lisa, M.T., "Terrain Categorization Using Multispectral and Multitemporal Imagery," Masters Thesis, Naval Postgraduate School, June 2000.

**DoD KEY TECHNOLOGY AREAS:** Sensors

**KEYWORDS:** Environmental Monitoring, Remote Sensing

### AURORAL X-RAY INFRARED IMAGING SATELLITE

**Richard C. Olsen, Associate Professor**

**Department of Physics**

**Sponsor: Secretary of the Air Force**

**OBJECTIVE:** Develop visible imager for the Naval Postgraduate School small satellite; proceed to PDR.

**SUMMARY:** The project was concluded at the design stage.

**THESIS DIRECTED:**

Robison, M., "Prototype Design of NPSAT Visible Imager," Masters Thesis, Naval Postgraduate School, June 2000.

**DoD KEY TECHNOLOGY AREAS:** Sensors

**KEYWORDS:** Environmental Monitoring, Remote Sensing

### CMO R&D TECHNICAL ASSISTANCE

**Richard C. Olsen, Associate Professor**

**Department of Physics**

**Sponsor: Defense Intelligence Agency**

**OBJECTIVE:** The proposed effort is to support the central MASINT Organization in its research and development efforts, particularly in the area of Spectral imagery and high frame rate non-imaging infrared systems. Technical development of the Cobra Brass F System, exploration of Cobra Brass E data and development of a UV Spectral Imager are supported.

**SUMMARY:** Significant progress was made with the Cobra Brass studies, including work in target tracking and aerosol discrimination. Work on a new UV spectrometer has begun.

## PROJECT SUMMARIES

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### **THESIS DIRECTED:**

Sukols, N.E., "Non-imaging Detection and Tracking of Mobile Targets," Masters Thesis, Naval Postgraduate School, September 2000.

**DoD KEY TECHNOLOGY AREAS:** Sensors

**KEYWORDS:** Environmental Monitoring, Remote Sensing

### **SENSOR FUSION FOR TERRAIN CATEGORIZATION**

**Richard C. Olsen, Associate Professor**

**Department of Physics**

**Sponsor: Navy Tactical Exploitation of National Capabilities (TENCAP) Office**

**OBJECTIVE:** The proposed research is to study the utility of data from National Technical Means (NTM) for Terrain Categorization (TERCAT). Data from visible, IR, and radar systems will be acquired in modes available to operational users, and analyzed according to the techniques currently in use for the interpretation of spectral imagery.

**SUMMARY:** Analysis was initiated on multi-temporal studies utilizing NTM systems.

**DoD KEY TECHNOLOGY AREAS:** Sensors

**KEYWORDS:** Environmental Monitoring, Remote Sensing

### **IR IMAGING SATELLITE STUDY**

**Richard C. Olsen, Associate Professor**

**Department of Physics**

**Sponsor: Defense Advanced Research Projects Agency**

**OBJECTIVE:** Study implementation of micro-bolometer focal plane technology for LWIR Spectral Imagery on a small satellite.

**SUMMARY:** A design study for a multi-spectral, LWIR sensor was completed, and delivered to the sponsor.

**DoD KEY TECHNOLOGY AREAS:** Sensors

**KEYWORDS:** IR Imaging, LWIR Spectral Imagery

### **MASINT RESEARCH IN SPECTRAL AND TEMPORAL SIGNATURES**

**Richard C. Olsen, Associate Professor**

**Department of Physics**

**Sponsor: Secretary of the Air Force**

**OBJECTIVE:** The proposed effort is to support the central MASINT Organization in its research and development efforts, particularly in the areas of Spectral Imagery and High Frame Rate Non-Imaging Infrared Systems. Technical development of the Cobra Brass F System, exploitation of Cobra Brass E Data, and development of AUV Spectral Imager are supported.

**DoD KEY TECHNOLOGY AREAS:** Sensors

**KEYWORDS:** Environmental Monitoring, Remote Sensing

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## PROJECT SUMMARIES

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### **RADIANT BRASS EXPLOITATION**

**Richard C. Olsen, Associate Professor**

**Philip L. Walker, Research Associate Professor**

**Department of Physics**

**Sponsor: Navy Tactical Exploitation of National Capabilities (TENCAP) Office**

**OBJECTIVE:** Develop a method for using satellite data to predict the performance of aircraft mounted FLIRs for desert operation.

**SUMMARY:** This project was funded for \$50K starting 1 May 2000. The project has 3 components. The first is to find a method of using satellite and meteorological data to determine atmospheric turbidity. The second is to test the method. The third is to relate satellite-derived turbidity to FLIR performance. The first two components are being worked in collaboration with Professor Durkee, NPS Meteorology and personnel at NAWC, China Lake. Ground-based equipment needed for validation of satellite retrieval of atmospheric optical depth is being operated at China Lake 24x7. This means the satellite operators can take their data at times most convenient to them. No satellite data has yet been received for analysis. It is expected that this situation will change shortly. Professor Durkee has offered to be a conduit for satellite data. He has been actively negotiating with the providers for processed data. Collaboration with Boeing has been discussed. They have volunteered to help obtain unprocessed satellite data. Meteorological information needed to extract turbidity from optical depth is to be generated using numerical weather prediction programs. We were to work the third component of this project using FLIRs mounted on F-18 being flown on training missions. That did not work out. Another approach is to try to piggyback on Predator UAV flights at Fallon. We will try that in late spring to early summer. Boeing is interested in arranging F-18 flights at China Lake.

**DoD KEY TECHNOLOGY AREAS:** Sensors

**KEY WORDS:** Environment, LIDAR, Transmission

### **WORKSHOP TO “BENCHMARK” THE EFFECTS OF SHALLOW WATER**

#### **ENVIRONMENTAL VARIABILITY**

**Kevin B. Smith, Associate Professor**

**Department of Physics**

**Sponsor: Office of Naval Research**

**OBJECTIVE:** To co-organize the proceedings of a workshop on shallow water environmental variability influences on underwater acoustic propagation modeling. This workshop investigated the effects of environmental variability, i.e., range, depth, and azimuthal variability, on acoustic signal propagation, the accuracy of the applied propagation models, and considered some limited signal processing of the modeled acoustic fields. Funding was provided during FY00 to support the review and editing process of submitted research articles.

**SUMMARY:** The SWAM99 (Shallow Water Acoustic Modeling) Workshop was held in Monterey, CA, Sep 89 1999, hosted by Professor Kevin Smith at NPS and co-chaired by Alex Tolstoy of Scientific Solutions, Inc. Attendance was about 30-35 researchers. It was a very successful meeting with a number of issues addressed, questions raised, and follows on problems suggested.

During FY00, Professor Smith and Dr. Tolstoy managed the collection, reviews, and submissions of manuscripts from SWAM99 participants for a special issue of the *Journal of Computational Acoustics*. This special issue will serve as the proceedings of the workshop.

#### **PUBLICATIONS:**

Smith, K.B., “Convergence, Stability, and Variability of Shallow Water Acoustic Predictions Using a Split-Step Fourier Parabolic Equation Model,” *Proceedings of the Shallow Water Acoustic Modeling (SWAM’99) Workshop*, 8-10 September 1999, *Journal of Computational Acoustics*, Vol. 9, No. 1, 2001 - Special Issue

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## PROJECT SUMMARIES

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of *Proceedings of the Shallow Water Acoustic Modeling (SWAM'99) Workshop*, 8-10 September 1999, (eds. Alex Tolstoy and Kevin B. Smith).

Tolstoy, A., Smith, K.B., and Maltsev, N., "The SWAM'99 Workshop - an overview," *Journal of Computational Acoustics*, Vol. 9, No. 1, 2001 - Special Issue of *Proceedings of the Shallow Water Acoustic Modeling (SWAM'99) Workshop*, 8-10 September 1999, (eds. Alex Tolstoy and Kevin B. Smith).

**DoD KEY TECHNOLOGY AREAS:** Modeling and Simulation

**KEYWORDS:** Shallow Water Variability, Underwater Acoustic Modeling

### REVERBERATION STUDIES IN EAST CHINA SEA

**Kevin B. Smith, Associate Professor**

**Department of Physics**

**Sponsor: Office of Naval Research**

**OBJECTIVE:** The objective of this research was to develop a model capable of computing the influence of propagation on both interface and volume reverberation from a broadband pulse. Spatial correlations and statistics of the predicted reverberant signal were examined. The results from further analysis will be used to compare such predictions with data collected in the upcoming ASIAEx experiments. By understanding the role of the acoustic propagation in such signals, a clearer description of the underlying dominant scattering mechanisms should emerge.

**SUMMARY:** The theoretical development of the PE reverberation model was completed with the exception of the inclusion of density fluctuations in the sediment volume. This will be added during FY01. Both interface roughness and sediment sound speed fluctuations were computed based on characteristic spectral models of such perturbations. These were incorporated into the PE model, and solutions of the acoustic propagation for both CW and broadband pulse sources were generated. During this development portion, only a single realization for both the interface and volume fluctuations was used in order to concentrate on the processing algorithms. The rms fluctuation of the interface was set to 1m while the volume sound speed rms fluctuation was fixed at 15m/s. Both types of perturbations were included in all calculations, although the reverberation due to each was considered separately. Thus, it is possible that one type of perturbation may dominate the structure of both types of reverberation. Further examination of the individual effects will be examined in FY01.

From both CW and broadband calculations, vertical spatial correlations of the reverberation field were computed. Additionally, the statistical characteristics of the reverberation signal are being examined. Such results from future calculations will eventually be compared with measured data to determine the influence of propagation and, hopefully, help discriminate specific scattering mechanisms.

#### **PUBLICATION:**

Smith, K.B. and Lit-Siew, L., "Broadband Parabolic Equation Modeling of Acoustic Bottom Interface and Volume Reverberation in Shallow Water," *Proceedings of 5th European Conference on Underwater Acoustics*, Lyon, France, 10-13 July 2000, pp. 1171-1176.

#### **PRESENTATION:**

Smith, K.B. and Lit-Siew, L., "Broadband Parabolic Equation Modeling of Acoustic Bottom Interface and Volume Reverberation in Shallow Water," 5th European Conference on Underwater Acoustics, Lyon, France, 10-13 July 2000, pp. 1171-1176.

## PROJECT SUMMARIES

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**DoD KEY TECHNOLOGY AREAS:** Modeling and Simulation

**KEYWORDS:** Shallow Water Reverberation, Parabolic Equation Modeling

### **MESOSCALE MODELING FOR ATMOSPHERIC TURBULENCE, PHASE II**

**D. L. Walters, Professor**

**Department of Physics**

**D. K. Miller, Research Assistant Professor**

**Department of Meteorology**

**Sponsor: Secretary of Air Force**

**OBJECTIVE:** To adapt state of the art of large mesoscale numerical models, MM5 and COAMPS for computing electro-optical parameters for National Technical applications.

**SUMMARY:** Refinements and errors in the Mellor y Yamada closure algorithm in the U.S. Navy Coupled Atmosphere Ocean Mesoscale Prediction (COAMPS) numerical model have been implemented so that the model can realistically predict optical turbulence. Two key results are that the National Weather Service ETA and U.S. Navy NOGAGS input data fields; produce larger changes in the model output than any of the versions of parameterization schemes that we have tried. Of the tests cases run to date, the ETA input data fields appears to provide results that are more consistent than the U.S. Navy Global NOGAPS model, but this conclusion may simply reflect differences in how the two global models handle certain situations.

#### **THESIS DIRECTED:**

Holdaway, A.R., "High Resolution Microthermal Balloon Measurements in Support of Adaptive Optical Programs," Masters Thesis, Naval Postgraduate School, June 2000.

**DoD KEY TECHNOLOGY AREAS:** Battlespace Environments

**KEYWORDS:** Atmospheric Turbulence, Adaptive Optics, Mesoscale Models, Adaptive Optical Systems, Imaging Systems

## PROJECT SUMMARIES

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### ATMOSPHERIC OPTICAL TURBULENCE SENSOR

**D. L. Walters, Professor**

**Department of Physics**

**D. K. Miller, Research Assistant Professor**

**Department of Meteorology**

**Sponsor: United States Air Force Starfire Optical Range**

**OBJECTIVE:** To develop and deliver a high resolution acoustic sonar for profiling optical turbulence use at USAF Starfire Optical range.

**SUMMARY:** NPS developed a prototype acoustic sonar for profiling optical turbulence in FY-98. This instrument was successfully used at the Starfire Optical Range to show that a large 1.5 m optical telescope facility had to be moved to a position on top of a hill to operate satisfactorily during the day. The USAF asked NPS to build and deliver a similar instrument for permanent installation. To be used in an unattended mode by unskilled technicians, the instrument had to be redesigned. A new power amp and preamplifier with remote power was designed, fabricated and tested, and a new sonar phased array with enclosure was designed and fabricated. This sonar enclosure had to have an automated rain cover and rain sensor to close when precipitation occurs. This system was developed, fabricated, tested and delivered on time within budget to the sponsor.

**DoD KEY TECHNOLOGY AREAS:** Battlespace Environments

**KEYWORDS:** Atmospheric Turbulence, Adaptive Optics, Adaptive Optical Systems, Imaging Systems